9p

UNPUBLISHED PRELIMINARY DATA

~~X64 10204~~

NASA CR 52473

[redacted]

FACILITY FORM 602

N65 81862
(ACCESSION NUMBER)

9
(PAGES)

CR 52473
(NASA CR OR TMX OR AD NUMBER)

(THRU)

None
(CODE)

(CATEGORY)

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70 Memorial Drive — Cambridge 42, Massachusetts, U.S.A.

-8

~~Re~~search Division
NATIONAL RESEARCH CORPORATION
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Cambridge ~~42~~, Massachusetts

6098008

NRC Project No. 81-1-0101

1 Sept

(9) Monthly Progress Report, September 1963

Contract No. NASw-734

INVESTIGATION OF ADHESION AND COHESION OF METALS IN ULTRAHIGH VACUUM

by

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(NASA Contract NASw-734; NRC/Proj. 81-1-0101)

(NASA CR-52473)

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September 16, 1963

FOREWORD

This report describes the progress made in September 1963 on work performed in the Research Division of National Research Corporation under Contract No. NASw-734 for the National Aeronautics and Space Administration.

The general object of the work is to obtain additional information as to the conditions under which metals and alloys of engineering importance for space applications will adhere to one another with sufficient tenacity to hinder the relative motion or subsequent separation of components of mechanical and electrical devices, used in space exploration. Such devices include bearings, solenoids, valves, slip rings, mating flanges, conical rendezvous mating surfaces and similar components.

ABSTRACT

After several more attempts to obtain a beam of xenon ions suitable for specimen cleaning by sputtering, work on the ion guns was postponed to permit the performance of additional adhesion tests. Two runs were made; one using flat faces as before after wire-brushing in vacuum, and one using chisel edged specimens meeting crosswise. In both runs soft copper was tried against soft copper, soft 1018 steel, soft 440C steel, soft 4140 steel, soft Cu-Be alloy and soft titanium.

In the second run, using the chisel edged specimens, soft 1018 steel was tried against soft 1018 steel and soft titanium against soft titanium. The chisel edged specimens were not wire brushed and in spite of the large amounts of deformation and sliding which occured, no adhesion was obtained even between soft copper specimens. Due to failure of the wire brushing device, large portions of the mating surfaces of the flat specimens were not touched by the brush. Adhesion occurred only between the flat faces of soft copper partially wire brushed in vacuum. It did not occur between soft copper specimens wire brushed in air and subsequently pressed together in vacuum.

ION GUN EXPERIMENTS

The ion guns were described in the first quarterly report. They are of the type which requires the establishment of a small volume of intensely ionized gas on one side of a small orifice and the extraction of ions into a relatively good vacuum on the other side of the orifice by a conical high voltage electrode. An axial magnetic field is provided to help keep the zone of ionization or plasma near the center. Some guns of this type use hot cathodes, and some use r-f to maintain the plasma on the high pressure (20 to 100 microns) side of the orifice. The amount of ion current obtainable from such guns depends largely on the degree of ionization of the gas just in front of the orifice. Obtaining current equivalent to complete ionization requires extremely intense arc type discharges and the attendant use of water cooling refractory materials, etc.

Since a flow of only .177 torr-liter/sec. represents one ampere of singly charged ions and since the flow of xenon involved (.010" orifice at 3×10^{-2} torr) is about 3×10^{-4} torr-liter/sec., complete ionization and extraction would correspond to about 1.0 ma.

Since only 10^{16} impingements should be required for cleaning and one ampere corresponds to 6.24×10^{18} impingement per second, a current of about 1 micro-ampere should be sufficient for cleaning in 1000 seconds. This means that at least 0.1% of the gas passing through the orifice must be ionized and guided to the specimen. It was felt that this should be possible using a low power r-f or d-c glow discharge at 10^{-1} to 10^{-2} torr, concentrated by permanent magnets.

The major difficulty has been the inability to see the discharge. It is believed that a simple r-f discharge between the inlet cone and the orifice plate, as originally planned, will suffice if windows for viewing the discharge are provided. The next step in perfecting the guns is to mount one in a glass tube on a separate system and run tests using argon.

ADHESION EXPERIMENTS

Two more runs were made in the adhesion testing apparatus. The materials tested, the testing conditions and the results of these are recorded in Tables 1 and 2.

In the first run (Table 1) flat specimens of the usual type were used in an attempt to determine whether soft copper would stick to other metals as tenaciously as to itself after wire brushing in vacuum. (This represents part of Task D - see First Quarterly Report.) Unfortunately, the wire brushing device became misaligned after brushing the first specimen pair and it was discovered on subsequent examination that only part of the surface of each specimen had actually been brushed. As shown in the table, no adhesion occurred except between soft copper and itself and even in this case the cohesive force was only half that previously measured for well brushed specimens.

As shown by Test No. 1 of Table 1, no cohesion occurs between soft copper if the wire brushing is done in air instead of in the vacuum. Therefore, the cleaning effect of the brushing must be

TABLE 1

Adhesion Run No. 3

P = 5 x 10^{-9} to 7 x 10^{-9} torr. Time in Contact = 60 Seconds. (250°C Bake Out)

Test No.	Material		Comp. Force (lbs.)	Contact Area (in.^{2})	Deformation (mils)		Cohesive Force lbs.	
	Top	Bottom			Top	Bottom		
1	Soft Cu	Soft Cu	2400	.0688	7.0	6.3	0+	Wire brushed in air only
2	Soft Cu	Soft Cu	2200	.0701	7.0	5.6	8	Partially brushed in vacuum++
3	Soft Cu*	Soft Cu	2400	.0655	5.2	5.4	60	Partially brushed in vacuum
4	Soft 1018 Steel	Soft Cu	2400	.0700	0	7.2	0	Partially brushed in vacuum
5	Soft 440C Steel	Soft Cu	2400	.0675	0	6.5	0	Partially brushed in vacuum
6	Soft 4140 Steel	Soft Cu	2400	.0688	0	5.0	0	Partially brushed in vacuum
7	Soft Cu-Be Alloy	Soft Cu	2400	.0662	0	6.0	0	Partially brushed in vacuum
8	Soft Titanium	Soft Cu	2400	.0663	0	6.5	0	Partially brushed in vacuum

* This sample was initially hard but was annealed during bake out

++ Subsequent examination of the specimens showed that, except for Test No.1, large portions of the contact areas remained unscratched by the brush. This resulted from binding of the brushing mechanism in Test No. 2.

\+ Joined and parted twice. No force measurements made the first time due to electrical difficulty.

TABLE 2

Adhesion Run No. 4

(Crossed 90° Chisel Edges)

$P = 7 \times 10^{-9}$ to 8×10^{-9} torr. Time in Contact = 60 Seconds. (250°C Bake Out)

Test No.	Material		Comp. Force (lbs.)	Deformation* (mils)		Cohesive Force lbs.
	Top	Bottom		Top	Bottom	
1	Soft Cu	Soft Cu	2400	68	68	0
2	Soft 440C Steel	Soft Cu	2400	0	104	0
3	Soft 4140 Steel	Soft Cu	2400	0	109	0
4	Soft Cu-Be	Soft Cu	2400	0	115	0
5	Soft Ti	Soft Cu	2400	0	108	0
6	Soft 1018 Steel	Soft 1018 Steel	2400	32	32	0
7	Soft Ti	Soft Ti	2400	20	20	0
8	Soft 1018 Steel	Soft Cu	2400	1	104	0

* Notch depth

more important than the roughening effect, and severe cohesion possibly equivalent to that observed in the previous program between freshly fractured surfaces, remains a possibility for really clean surfaces. Only comparison with some other cleaning method such as ion bombardment or grinding or machining in vacuum will resolve the matter - since we cannot be sure how thorough the wire brush cleaning is, even when all the surface appears to have been scratched by the brush.

In the second adhesion test run (see Table 2) a new kind of specimen was used. The usual 45° beveled edges previously used to define the width of the flat face were widened till they met at the center, forming a 90° chisel edge (zero face width). Thus a test consisted of pushing crossed chisel edges together at right angles to one another. This was done in order to provide a large amount of deformation with the force available, i.e. to simulate severe roughness or mismatch. Specimen pairs of both equal and unequal hardness were represented as shown by the table. For equal hardnesses the deformation was equal on each side and little or no sliding occurred. For unequal hardnesses all of the deformation occurred in the softer specimen and severe sliding must have occurred. No wire brushing was attempted. In spite of the large amounts of deformation and sliding no measurable adhesion occurred.

This was an unexpected result, and must mean that the oxide layer on copper can withstand considerable stretching and sliding without rupture. It also means that deformation and sliding though possibly necessary are not always sufficient conditions for adhesion. It is believed that no mobile adsorbed films were present at 8×10^{-9} torr after the 250°C bake out. It is almost a foregone conclusion that severe cohesion would have occurred, at least between the two soft copper specimens, had wire brushing or other effective cleaning method been used. In fact, this type of specimen looks very promising for classification of material pairs according to their sticking tendencies. Ion bombardment cleaning is even more efficient at an impingement angle of 45° (normal to a chisel edge) than at 90°. These experiments terminate the experimental program.

Continuation of these tests using various cleaning methods seems well worthwhile. Numerous specimens are on hand.

FUTURE PLANS

Drafting of the final report will begin at once. The final report will contain recommendations for further studies.